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OCTOBER 1957

Drag And Stability Properties Of The 37-mm T324-E22 Shell (U)

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EUGENE D. BOYER

DEPARTMENT OF THE ARMY PROJECT NO. 5B03-03-001
ORDNANCE RESEARCH AND DEVELOPMENT PROJECT NO. TB3-0108

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BALLISTIC RESEARCH LABORATORIES

ABERDEEN PROVING GROUND, MARYLAND

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Eugene D. Boyer

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MEMORANDUM REPORT No. 1107

EDBoyer/iw
Aberdeen Proving Ground, Md.
October 1957

DRAG AND STABILITY PROPERTIES OF THE 37-mm T324-E22 SHELL (U)

ABSTRACT

The aerodynamic properties of the 37-mm T324-E22 shell as determined from Transonic Range firings are presented.

TABLE OF SYMBOLS

M	Mach number
K_D	drag coefficient
K_M	overturning moment coefficient
K_L	lift coefficient
K_H	moment coefficient due to cross angular velocity
K_{MA}	moment coefficient due to cross acceleration
K_T	Magnus moment coefficient
$\lambda_{1,2}$	yaw damping rates
$\overline{\delta^2}$	mean squared yaw
K_{10}	magnitude of nutational yaw arm at mid range
K_{20}	magnitude of precessional yaw arm at mid range
A	axial moment of inertia
B	transverse moment of inertia
cm	center of mass
d	diameter
N	number of yaw observations
N_T	number of timing observations
S_L	swerve associated with the lift force
ϵ_Y	error in yaw fit
ϵ_S	error in swerve fit
$\phi'_{1,2}$	nutational and precessional turning rates
s	gyroscopic stability factor
$\bar{s}$	dynamic stability factor

INTRODUCTION

At the request of the Computing Laboratory the 37mm T324-E22 shell was fired through the Transonic Range of the Exterior Ballistic Laboratory. These firings were conducted to determine the drag coefficient for the preparation of firing tables. A photograph of the shell is shown in Figure 1. The physical properties are given in Figure 2.

The program consisted of firing 19 rounds over a range of Mach numbers, M = 0.6 to M = 2.7, from the M3A1 tube mounted in a Frankford rest (Fig. 3). This tube has a twist of 1 turn in 17 calibers of travel. Initial firings exhibited very little yaw. Since two to three degrees of yaw are desired to determine the aerodynamic properties of the shell it became necessary to induce yaw. This was done by installing a blast deflector (Fig. 4) on the muzzle of the tube. This device distorts the flow of the gun gases over the model just after ejection and gives the model a tipping tendency. One round was fired at each Mach number with the deflector on the tube.

Three rounds were fired at the service velocity of 3000 fps. It was observed that one round lost its fuze cap after 580 feet of flight. A shadowgraph of the shell is given in Figure 5 and a shadowgraph of the shell with the fuze cap detached is given in Figure 6. At the conclusion of the scheduled program an additional 11 rounds were fired to try and duplicate this phenomenon. The fuze caps were intact on all of these rounds within the observed portion of the trajectory and no other information is reported from these rounds. It must be noted that the loss of a fuze cap was observed from a very limited firing program. This loss may have been due to one freak round, or it may be an indication of marginal strength of the fuze cup. Since the limited sample fired in this report can not differentiate these possibilities it is suggested that if short ranges are observed in future firings of this shell that this phenomenon be studied further. The round that lost its fuze cap had been fired when using the blast deflector but it is felt that the deflector would not interfere with the fuze cap. The drag coefficient for a shell without the fuze cap is increased by a factor of two.

RESULTS AND CONCLUSIONS

The data are given in the table of aerodynamic data and in Figures 7 to 14.

Drag:

The drag force coefficient, K_D, and Mach number were determined for each round from the test conditions and a polynomial leat squares fit of time-distance data taken in the test. Since drag is both a function of Mach number and yaw it is desirable to separate the effects of these two. Assuming that drag is a linear function of mean squared yaw, K_D was reduced to zero yaw by the relationship $K_D = K_{D_0} + K_{D_{\delta^2}} \overline{\delta^2}$. Due to the limited amount of data at any one Mach number it was impossible to determine a yaw drag coefficient, $K_{D_{\delta^2}}$, over the entire range of Mach numbers. However, $K_{D_{\delta^2}}$ was reasonably determined to be 2.0 1/radians square at M = 2.6. This 2.0 value was used at all Mach numbers to determine the zero yaw drag coefficient as given in Figure 7. At supersonic velocities $Q = \sqrt{1 + M^2 K_{D_0}} = a + bM$, where a and b are empirical constants, is a useful smoothing formula.[1] A Q function was fitted for drag values between M = 1.32 and M = 2.67, yielding:

$$a = 0.9280 \pm 0.0037 \text{ s.d.}$$
$$b = 0.1581 \pm 0.0016 \text{ s.d.}$$

Overturning Moment and Lift:

The moment coefficient, K_M, was determined from the turning rates of the two arms of the characteristic epicyclic yawing motion of a spinning missile (Fig. 8).[2] This K_M yields a gyroscopic stability factor of 3 which is certainly adequate for the shell. The lift force coefficient, K_L, is determined from the analysis of the swerving motion (Fig. 9). The center of pressure of the normal force is given in Figure 10.

Dynamic Stability:

A shell is considered to be dynamically stable if its transient yawing motion does not increase with time.[3] From the yaw damping rates (Figs. 11 and 12) it is seen that the precessional rate is undamping at speeds less than $M = 1.5$. This shell is being considered for use at slant ranges up to 5200 yards. With a muzzle velocity of 3000 fps the shell will enter the unstable region at about 2200 yards and remain there during the rest of its flight. However, the degree of instability is slight and if the indicated trends continue, an initial yaw of two degrees would yield a terminal yaw on the order of 10 degrees*. The instability is primarily due to the Magnus moment, K_T, which is positive for $M < 1.8$ (Fig. 13). The damping moment, $K_H - K_{MA}$, is positive at supersonic velocities and becomes slightly negative at low subsonic velocities (Fig. 14) and hence also contributes to instability in this region.

EUGENE D. BOYER

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*Also, for shell flying at low velocities, the dynamic stability is frequently sensitive to yaw level due to nonlinearities of some of the aerodynamic properties. Conventional shell, at high subsonic speeds, usually show instability when fired at small yaw; that is, when the shell is fired at small yaw the yaw will grow. As the yaw grows, however, the aerodynamic properties change in such a way that the shell becomes stable at some yaw level other than zero.[4] This case of low yaw instability and higher yaw stability may exist for the 37mm T324-E22 shell for $M < 1.5$. However, the available data are too limited to demonstrate this.

REFERENCES

1. Thomas, R.N., Some Comments on the Form of the Drag Coefficient at Supersonic Velocity, BRL Report 542 (1945).

2. Murphy, C.H., Data Reduction for the Free Flight Spark Ranges, BRL Report 900 (1954).

3. Murphy, C.H., On Stability Criteria of the Kelley-McShane Linearized Theory of Yawing Motion, BRL Report 853 (1953).

4. Roecker, E.T., The Aerodynamic Properties of the 105mm HE Shell, M1, in Subsonic and Transonic Flight, BRL Report 929 (1955).

TABLE OF AERODYNAMIC DATA

37-MM T324

Round Number	M	K_D	K_M	K_L	$K_H - K_{MA}$	K_T	$\lambda_1 \times 10^3$ $(ft)^{-1}$	$\lambda_2 \times 10^3$ $(ft)^{-1}$	$\overline{\delta^2}$ $(deg)^2$
4442T	.651	.0993	1.42	.82	-.7	.26	1.16	-.94	11.69
4441	.679	.1102	1.46	.77	-.1	.19	1.02	-.54	23.81
4443T	.843	.1080	1.51	.79	.4	.18	1.20	-.54	15.87
4440	.860	.0981	1.63	.81					2.49
4444T	.936	.1043	1.61	.85					2.96
4439	1.014	.1751	1.52	.75	2.9	.08	1.70	-.01	14.75
4445T	1.038	.1745	1.52	.72	3.0	.13	2.07	-.38	12.87
4438	1.049	.1612	1.60	.75					2.44
4446T	1.140	.1673	1.58	.82	3.0	.20	2.49	-.71	5.05
4437	1.148	.1676	1.58	.73	3.3	.16	2.39	-.55	6.27
4436	1.279	.1628	1.58	.77	3.5	.12	2.27	-.32	4.09
4447T	1.323	.1674	1.56	.74	3.1	.14	2.19	-.44	5.31
4435	1.677	.1552	1.56	.77	4.4	.01	1.95	.37	3.97
*4463T	1.715		1.48	.88	3.3	.06	1.75	.16	5.71
4434	2.170	.1309	1.45						.76
4448T	2.180	.1323	1.39						1.39
4451	2.643	.1252	1.28	.95	3.4	-.04	1.21	.81	15.06
4450	2.654	.1184	1.28	.88	5.1	-.09	1.65	1.02	3.96
**4449T	2.672	.1162	1.15		3,3	-.02	1.67	.56	2.70

* Nose damaged before firing

** Wind shield came off after 550 feet of flight. Data computed for first 530 feet.

T Fired with blast deflector

TABLE OF AERODYNAMIC DATA

37-MM T324

Round Number	M	N	N_T	K_{10} (rad)	K_{20} (rad)	S_L (ft)	ϵ_Y (rad)	ϵ_S (ft)	ϕ_1' (deg/ft)	ϕ_2' (deg/ft)	s	$\bar{s}$
4442T	.651	19	9	.023	.054	.06	.0034	.0083	12.90	1.29	3.03	
4441	.679	23	10	.041	.073	.08	.0031	.0133	12.87	1.27	3.07	
4443T	.843	25	11	.034	.059	.06	.0028	.0113	13.15	1.27	3.11	
4440	.860	23	9	.002	.022	.02		.0087	13.15	1.37		
4444T	.936	25	13	.001	.027	.03		.0092	13.71	1.30		
4439	1.014	18	10	.033	.054	.06	.0023	.0089	13.84	1.21	3.37	
4445T	1.038	22	12	.025	.055	.06	.0034	.0121	13.50	1.24	3.24	
4438	1.049	23	12	.006	.025	.02		.0094	13.62	1.30		
4446T	1.140	25	12	.014	.034	.04	.0027	.0098	13.38	1.31	3.08	
4437	1.148	21	10	.016	.039	.04	.0029	.0080	13.48	1.30	3.11	
4436	1.279	22	7	.011	.033	.03	.0032	.0090	13.29	1.32	3.04	
4447T	1.323	22	13	.019	.033	.03	.0047	.0079	13.19	1.30	3.05	
4435	1.677	22	10	.018	.028	.03	.0031	.0089	13.25	1.30	3.06	.43
*4463T	1.715	22	---	.028	.033	.04	.0044	.0091	13.25	1.21	3.25	.29
4434	2.170	22	7	.008	.012	.01			13.45	1.19		
4448T	2.180	20	9	.012	.015	.02			13.44	1.14		
4451	2.643	23	12	.047	.046	.08	.0037	.0077	13.30	1.07	3.64	.83
4450	2.654	22	11	.030	.030	.05	.0041	.0098	13.37	1.06	3.59	.80
**4449T	2.672	19	9	.019	.021	.03	.0028	.0078	13.22	1.09	3.55	.58

* Nose damaged before firing

** Wind shield came off after 550 feet of flight. Data computed for first 530 feet

T Fired with blast deflector

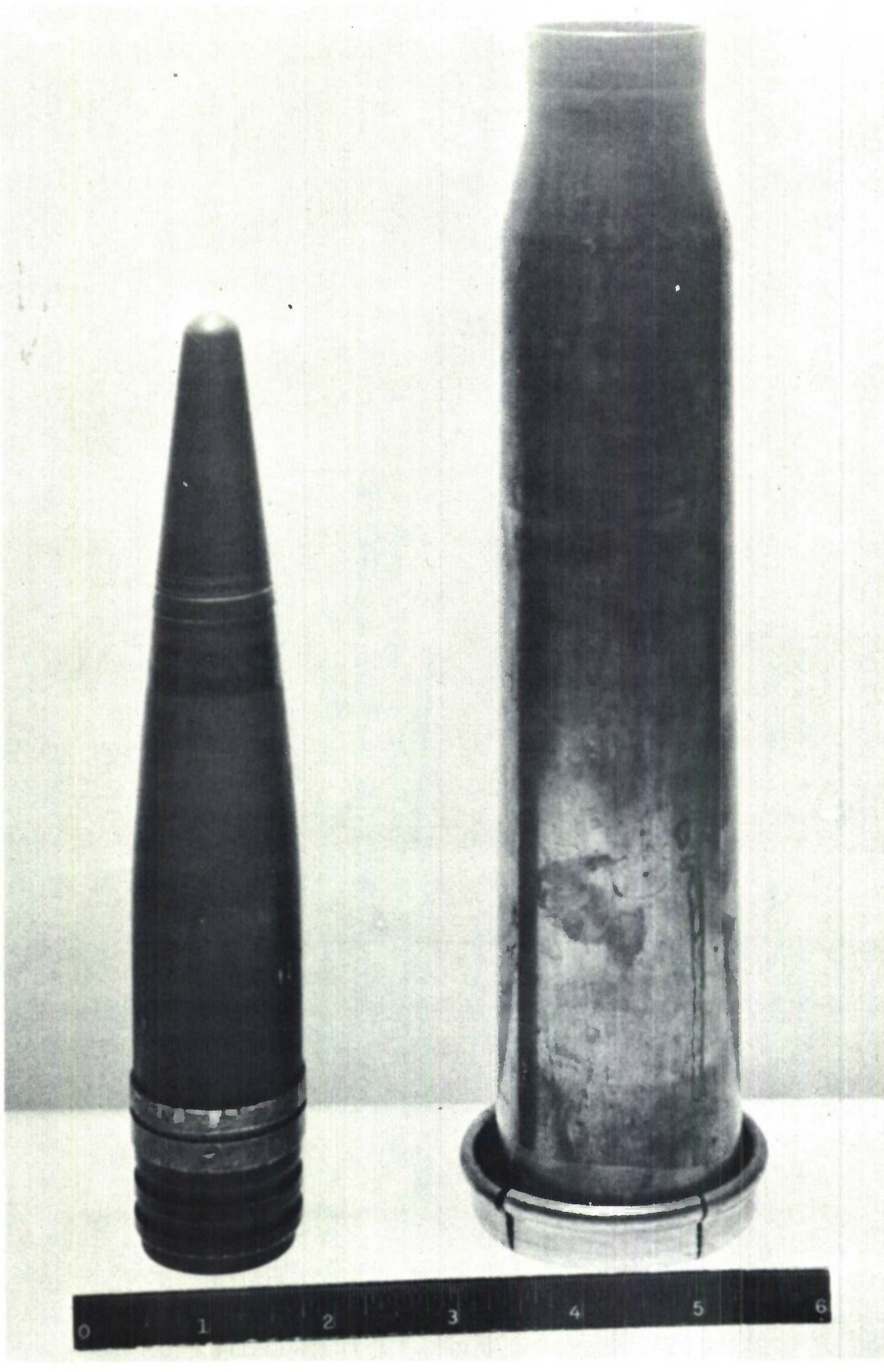
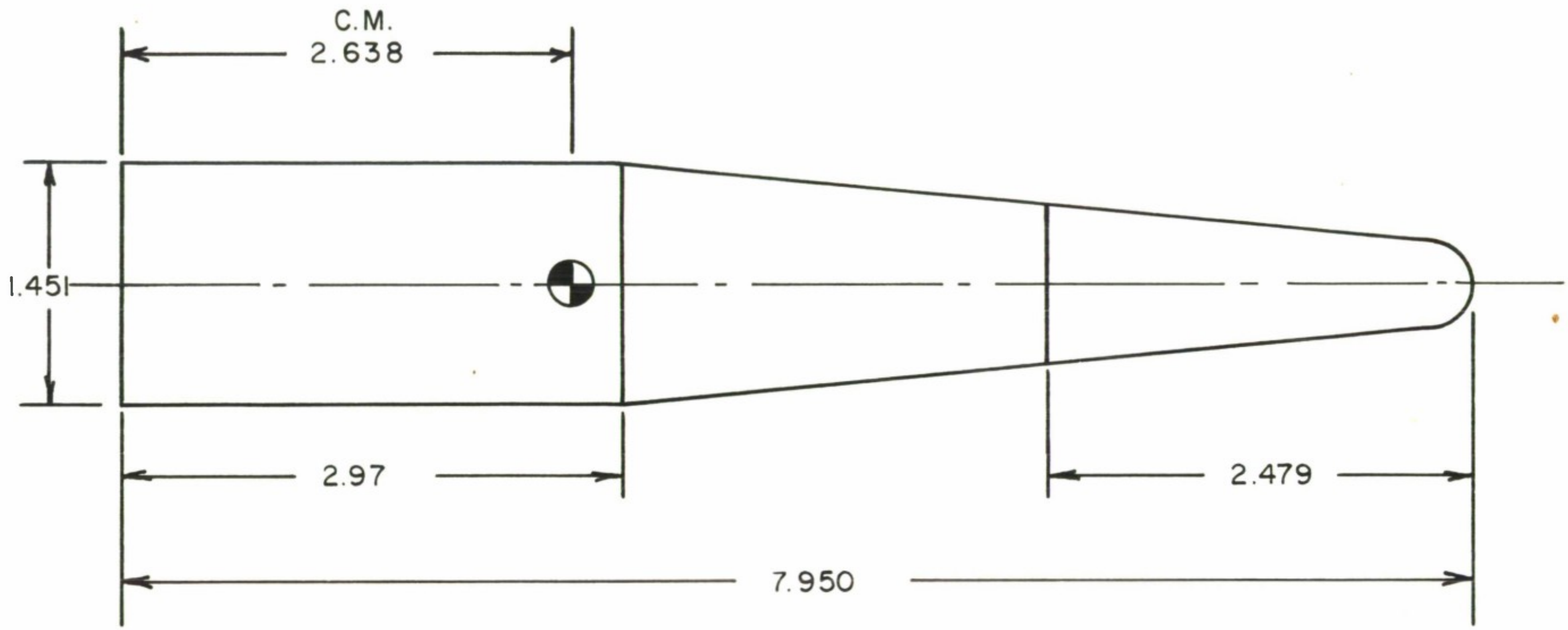


FIGURE 1
T324-E22
Shell

PHYSICAL PROPERTIES



WT = 1.65 lb.

A = .46 lb.-in.^{2}

B = 5.68 lb.-in.^{2}

NOTE: All Dimensions are in Inches

FIG. 2

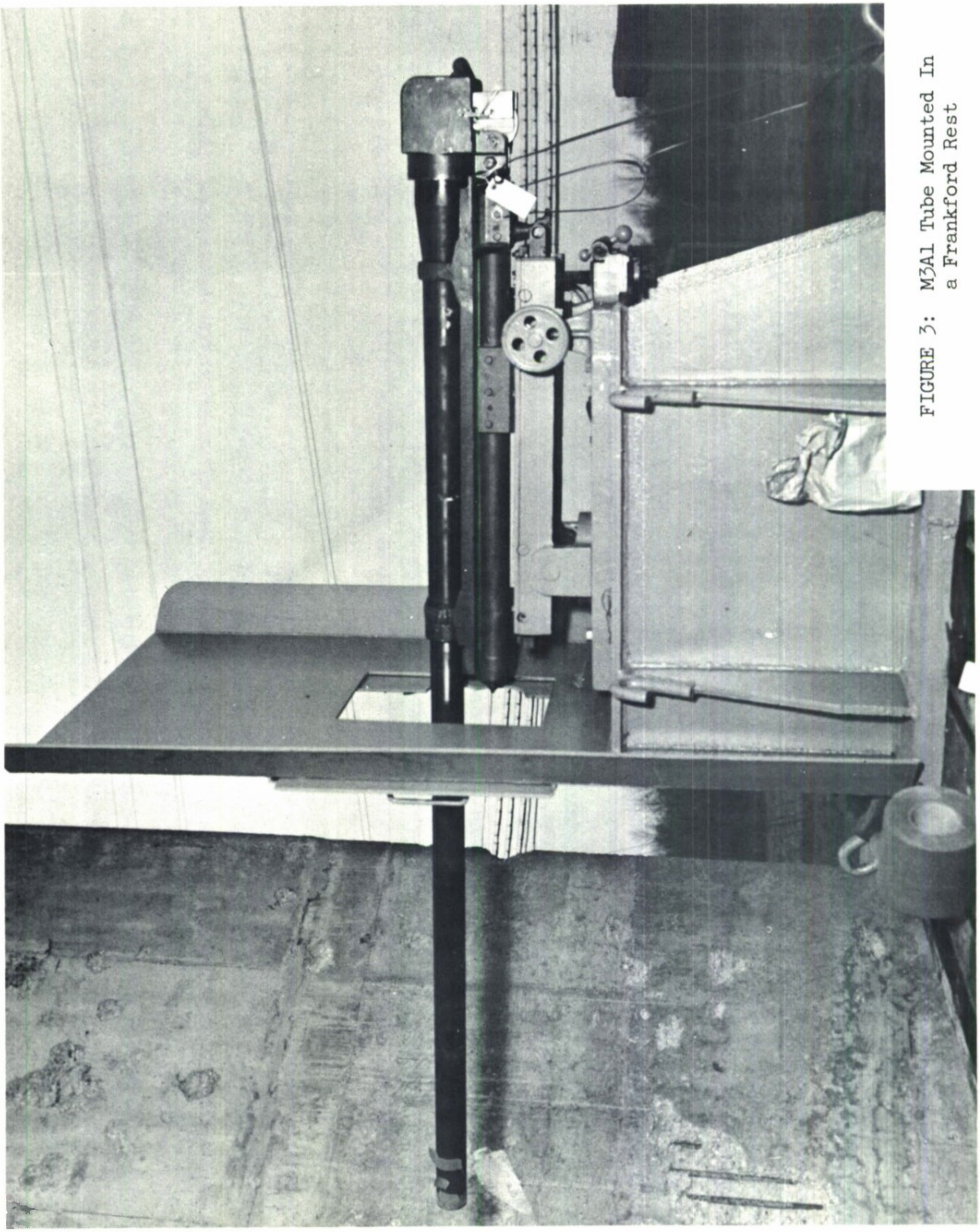


FIGURE 3: M3A1 Tube Mounted In a Frankford Rest

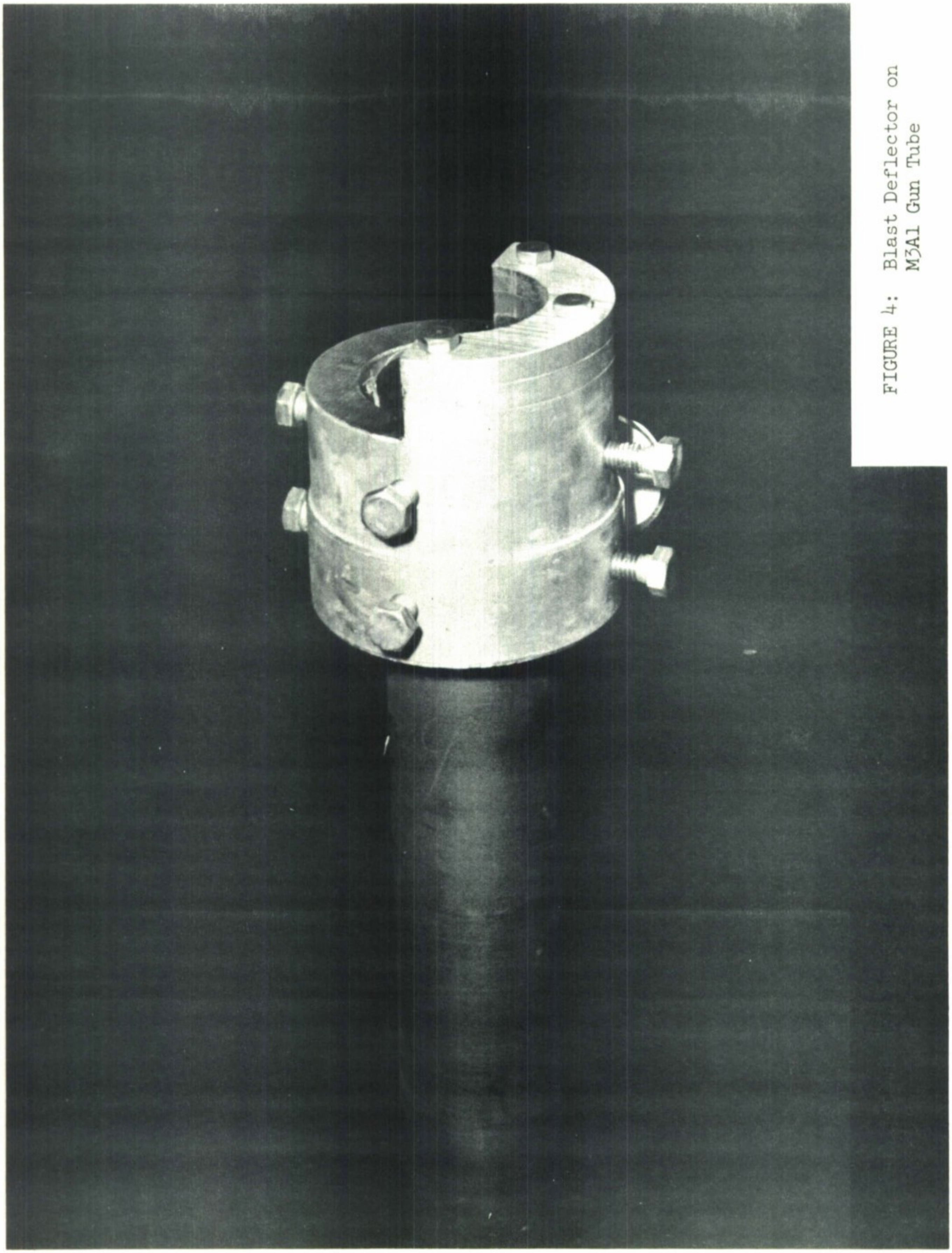


FIGURE 4: Blast Deflector on M3A1 Gun Tube

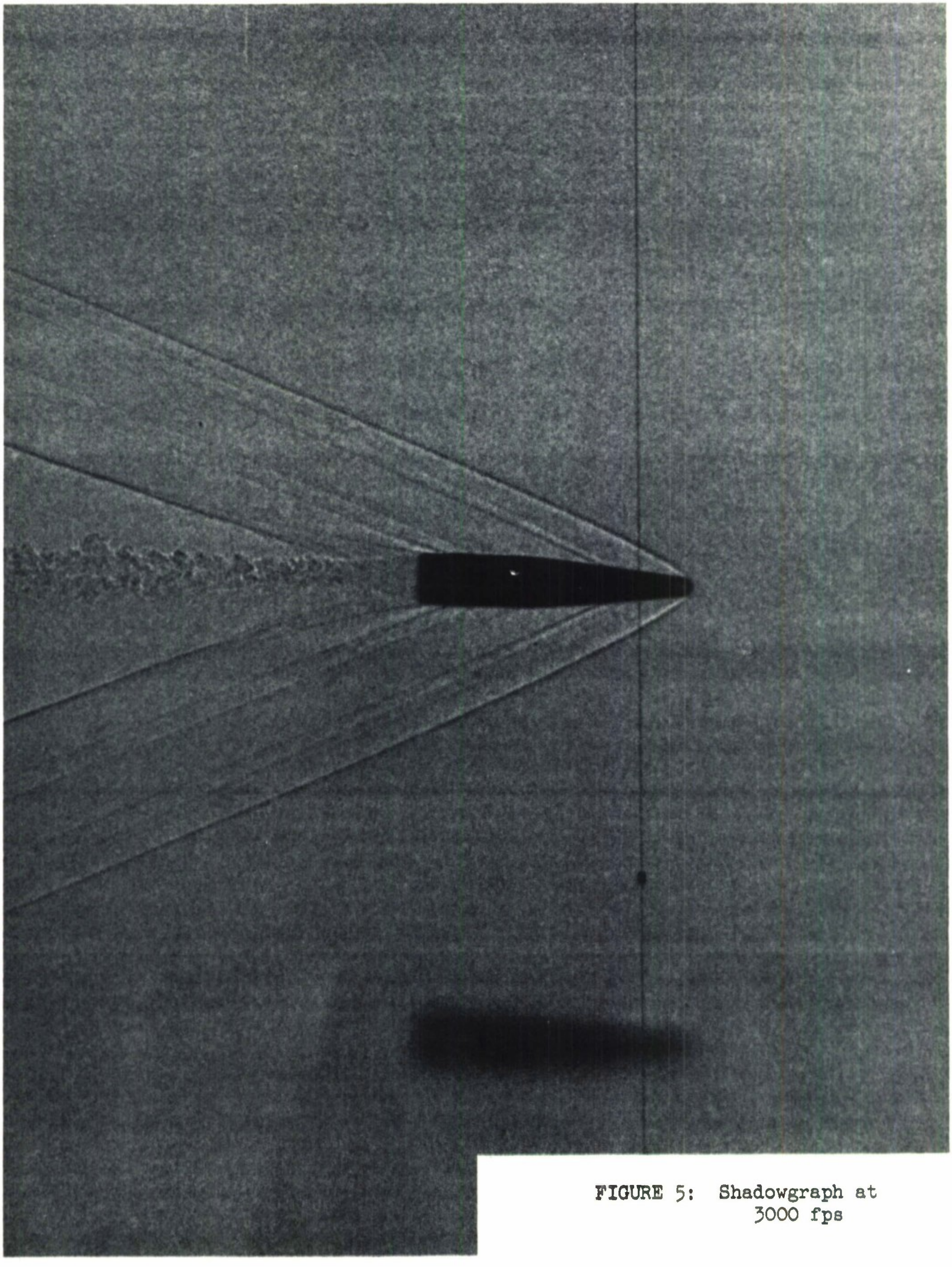


FIGURE 5: Shadowgraph at 3000 fps

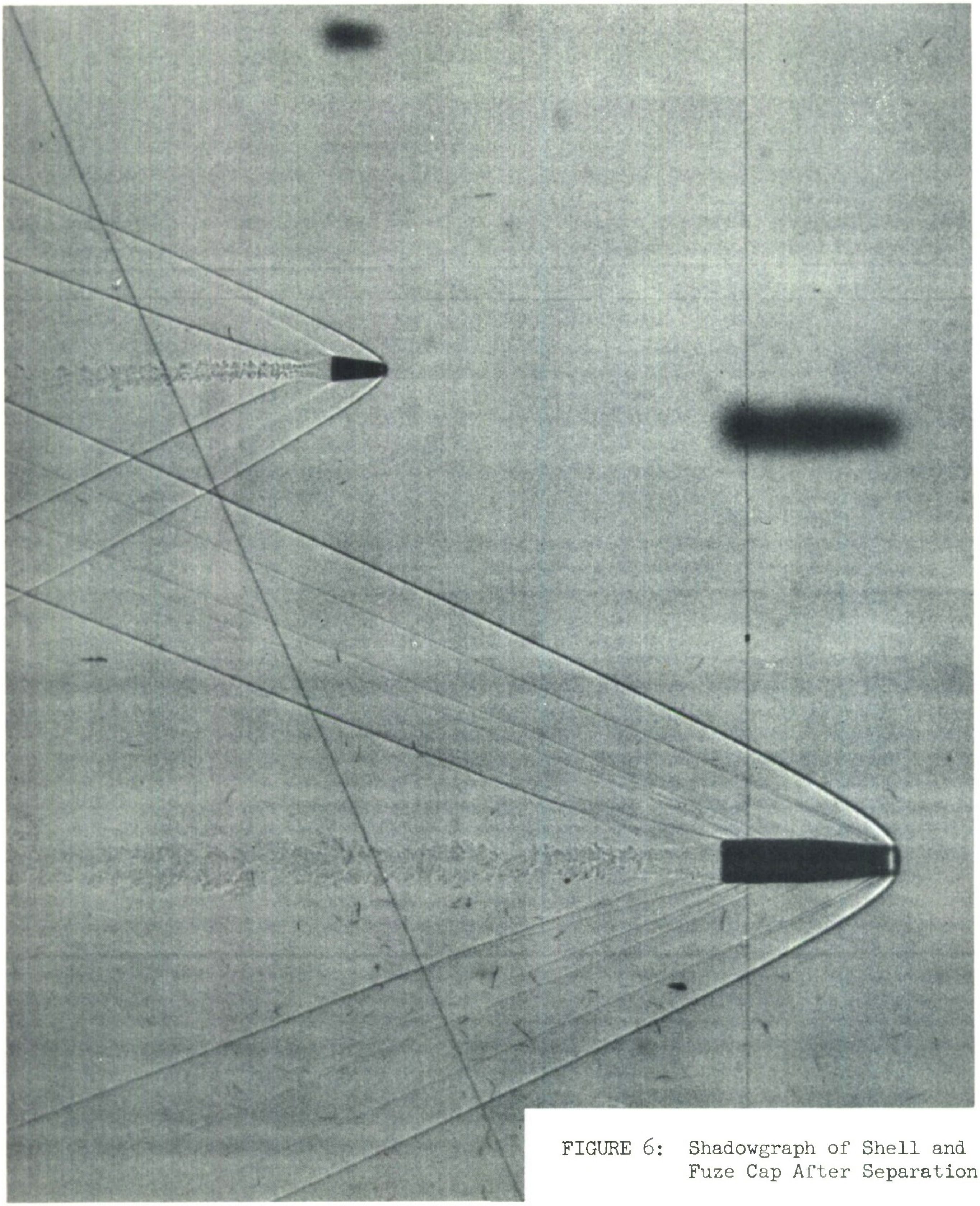


FIGURE 6: Shadowgraph of Shell and Fuze Cap After Separation

ZERO-YAW DRAG COEFFICIENT
vs
MACH NUMBER

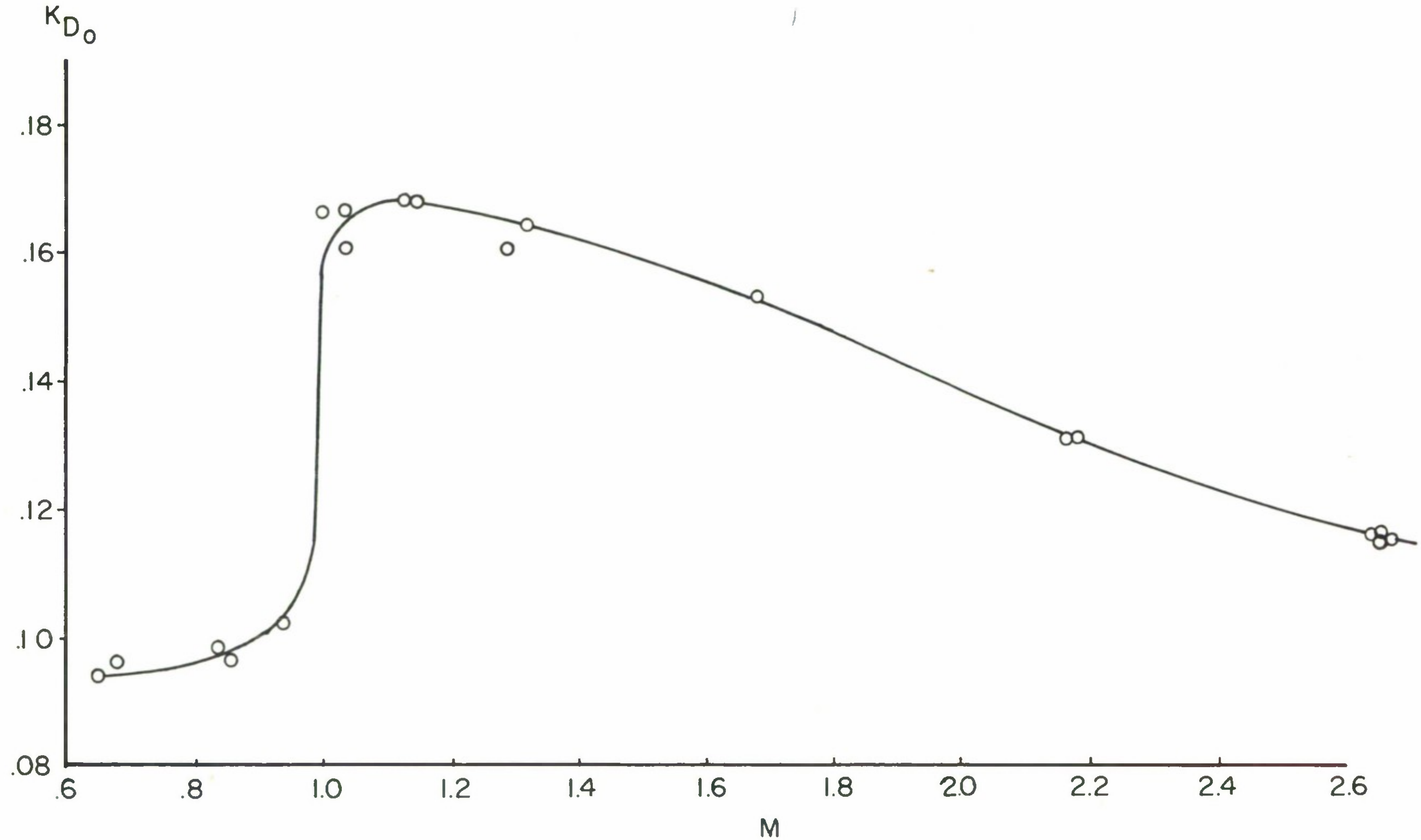


FIG. 7

OVERTURNING MOMENT COEFFICIENT
vs
MACH NUMBER

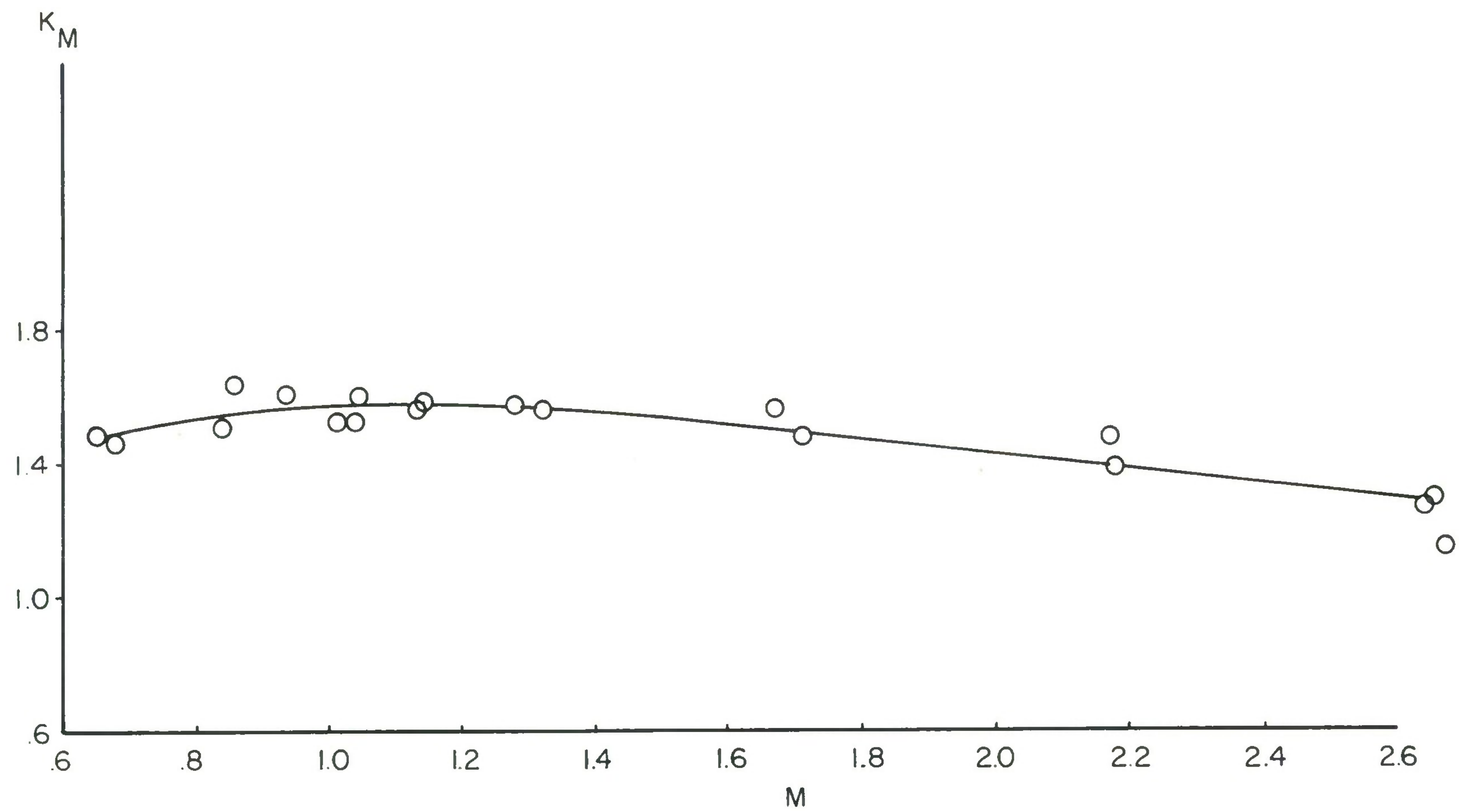


FIG. 8

LIFT FORCE COEFFICIENT
vs
MACH NUMBER

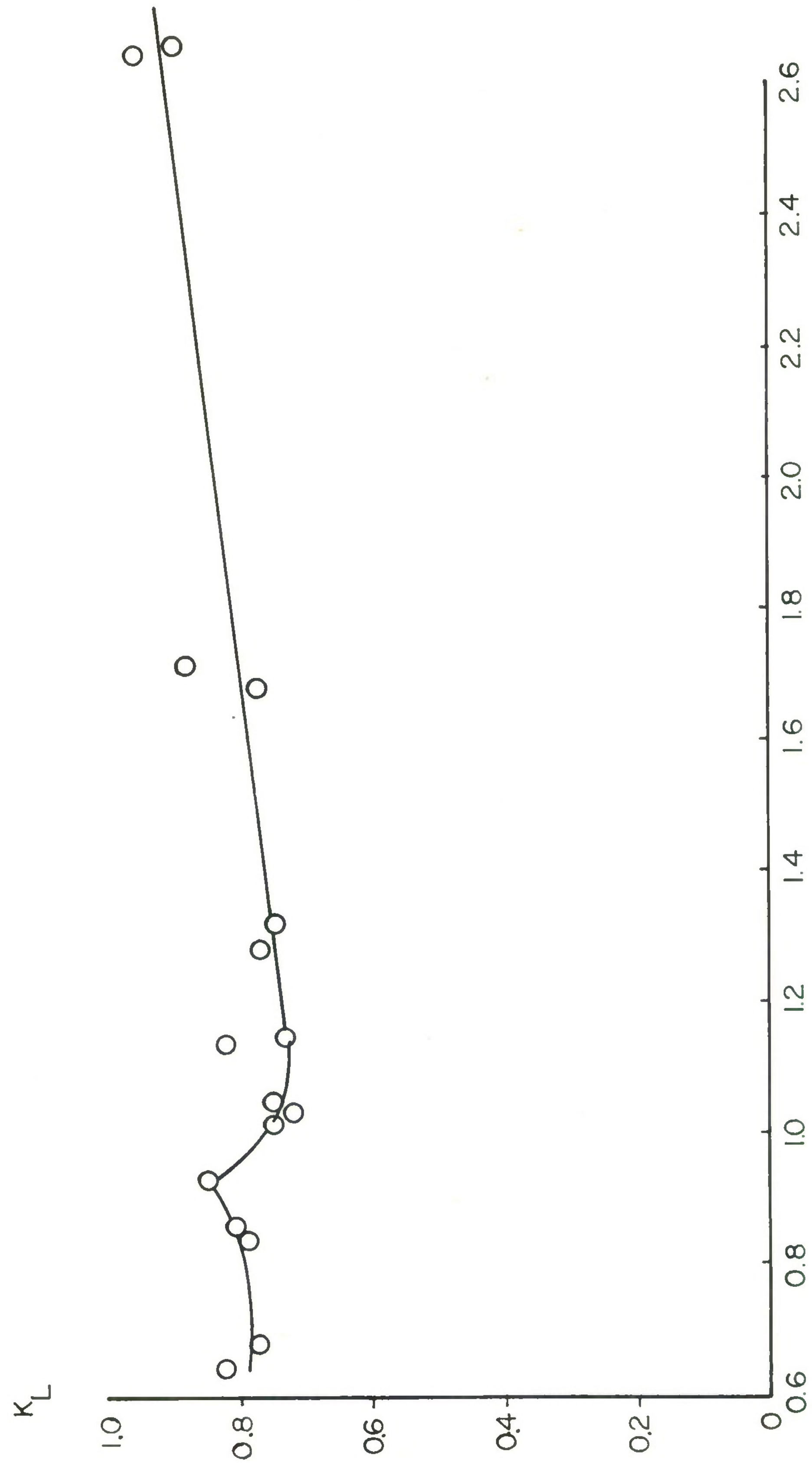


FIG. 9

NORMAL FORCE CENTER OF PRESSURE
vs
MACH NUMBER

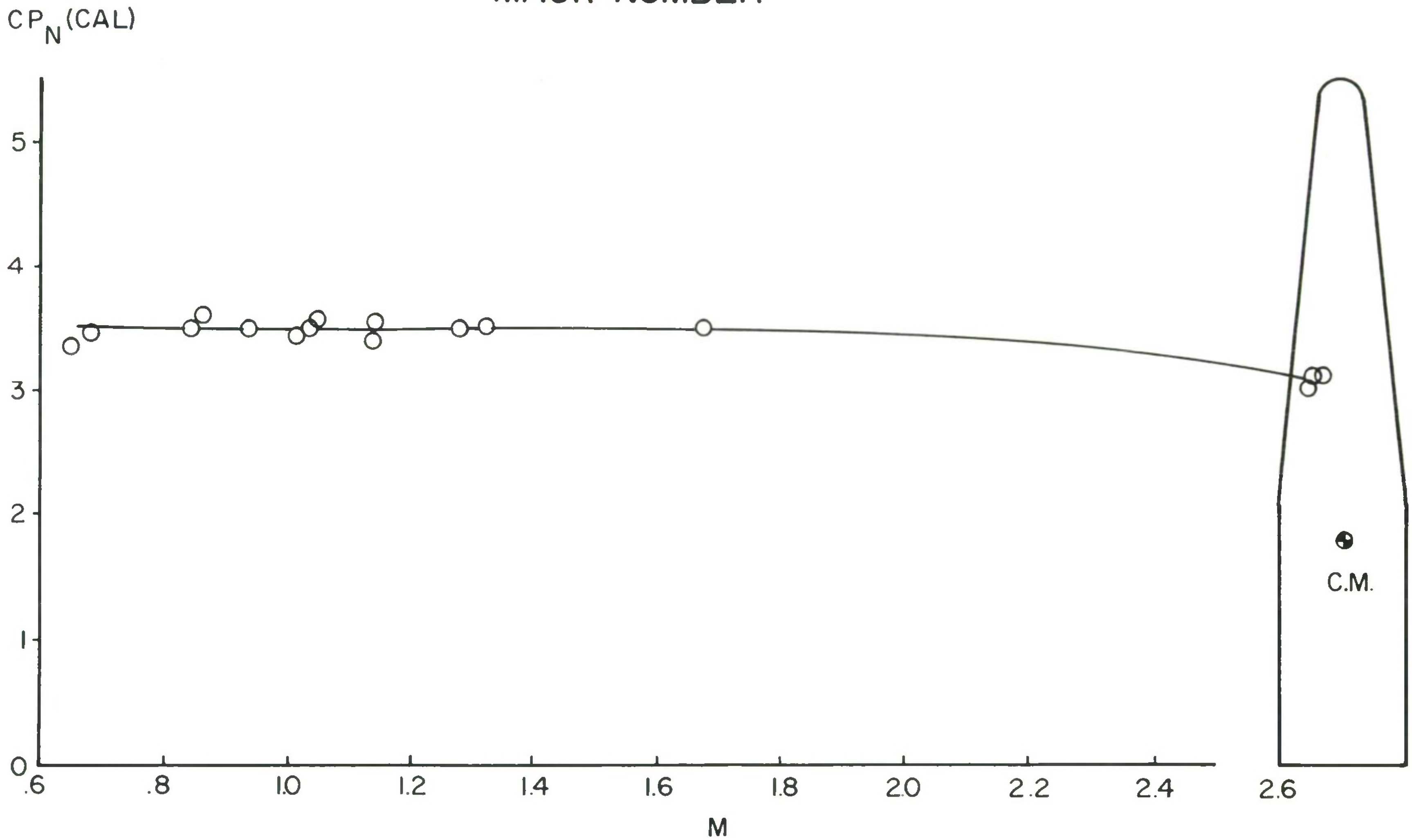


FIG. 10

NUTATIONAL YAW DAMPING RATE, $e^{-\lambda_1 Z}$
vs
MACH NUMBER

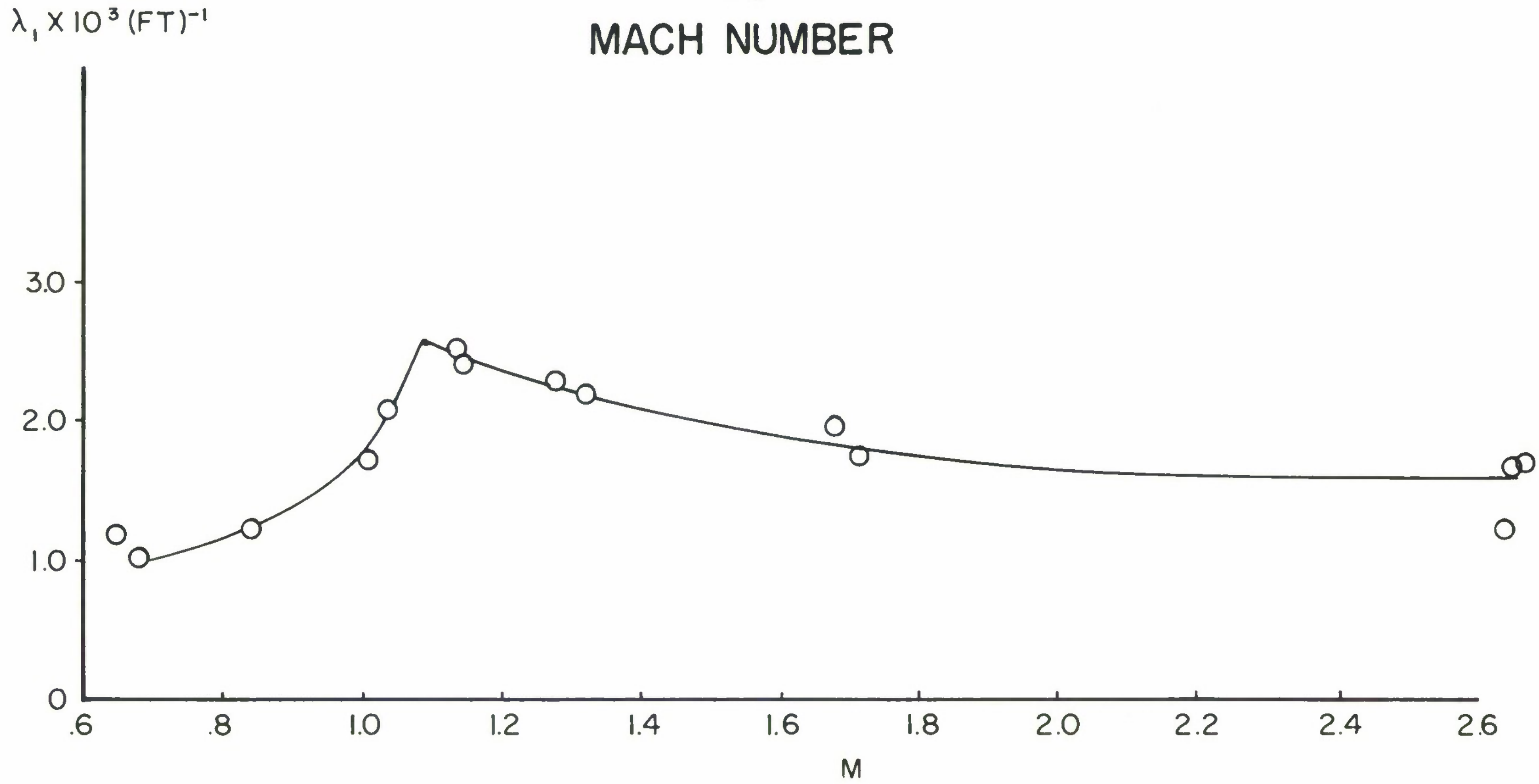


FIG. 11

PRECESSIONAL YAW DAMPING RATE, $e^{-\lambda_2 Z}$
VS
MACH NUMBER

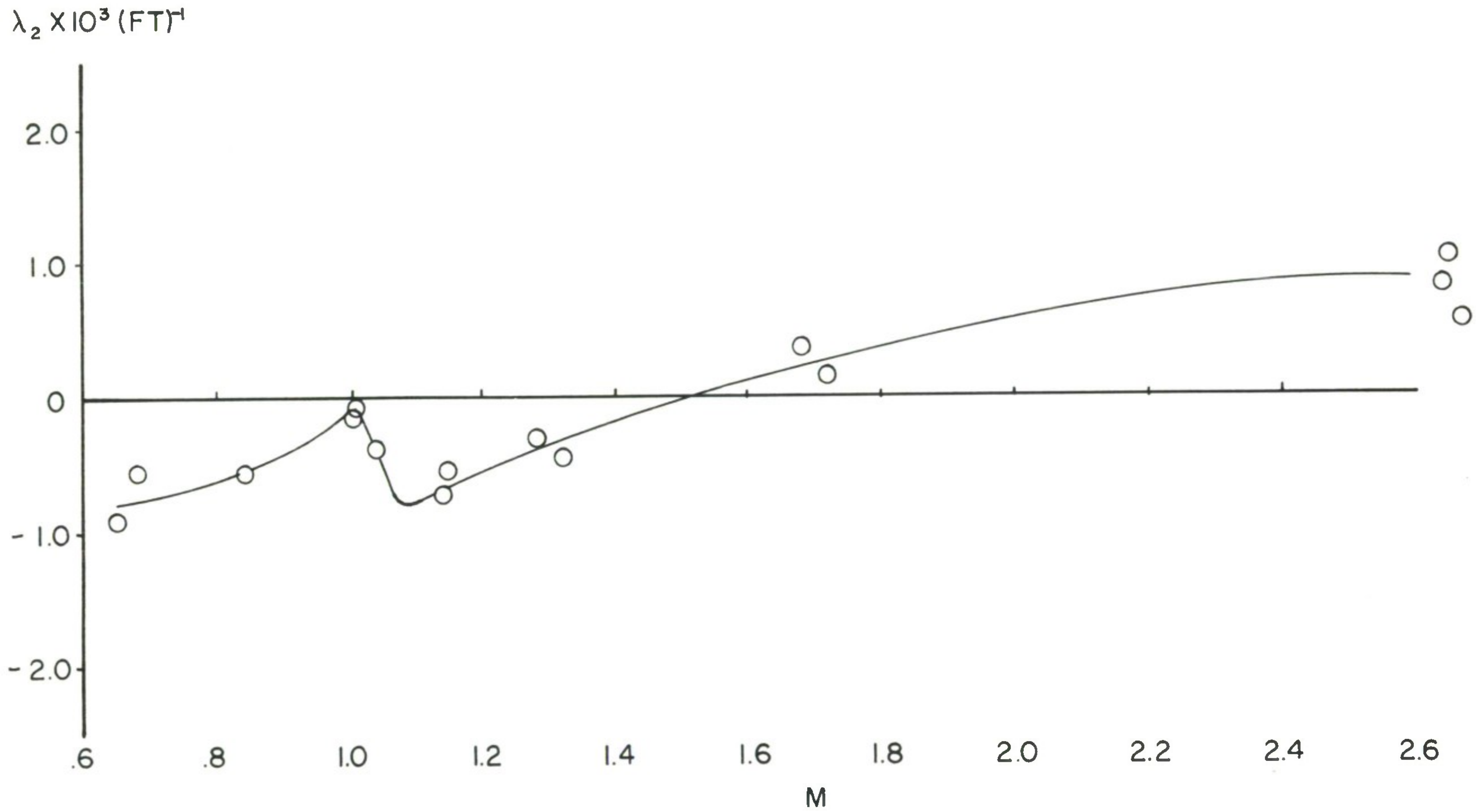


FIG. 12

MAGNUS MOMENT COEFFICIENT vs MACH NUMBER

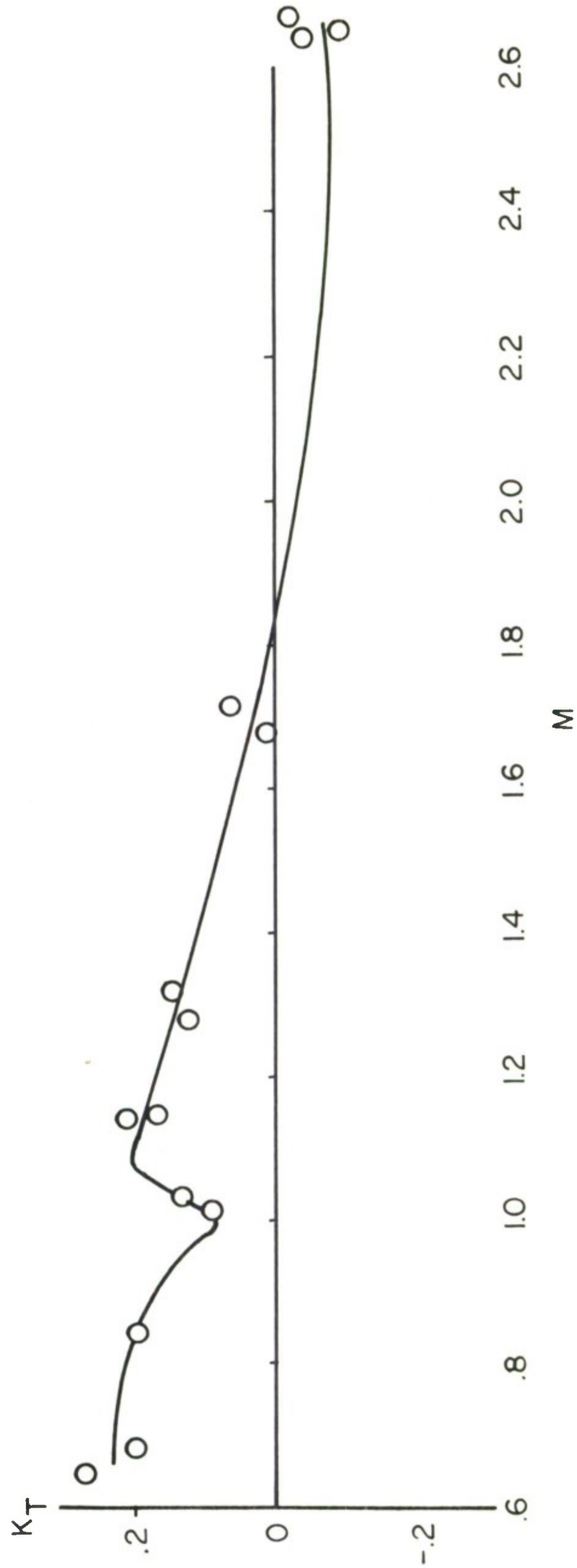


FIG. 13

DAMPING MOMENT COEFFICIENT
VS
MACH NUMBER

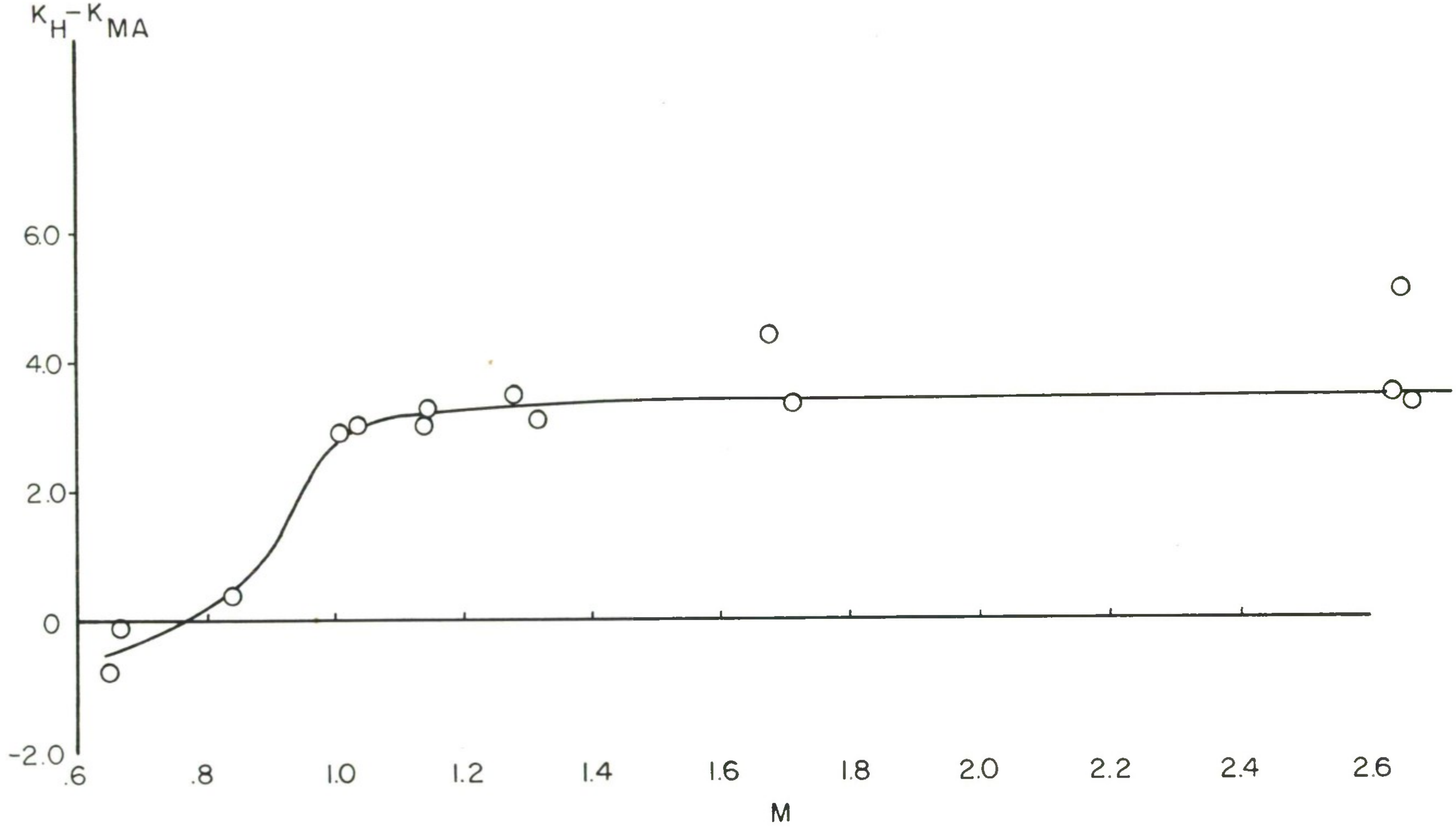


FIG. 14

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